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An assessment of forest biomass maps in Europe using harmonized national statistics and inventory plots

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ABSTRACT

Maps of aboveground forest biomass based on different input data and modelling approaches have been recently produced for Europe, opening up the possibility for several applications and products not obtainable by summary statistics. However, the accuracy assessment of the existing maps is limited by the lack of reference data consistent over the study region and representative of the maps cells. Here, we used harmonized forest biomass data for 26 European countries derived by National Forest Inventories using a common biomass definition and estimator to assess four biomass maps. The assessment was performed at regional, national and sub-national scales using harmonized statistics derived from almost half million ground plot measurements, and at pixel level using a subset of 22,166 plots covering most European forest types. The field plots were temporally aligned with the maps using growth rates and further screened using an innovative approach based on tree cover variability to remove the plots not representative of the map cells. The harmonized reference data showed that all maps tended to overestimate at low biomass ($< 100\,Mg\,ha^{-1}$) and underestimate at medium – high biomass ($> 100\,Mg\,ha^{-1}$), resulting in an overall negative bias (23–43 $Mg\,ha^{-1}$ at national level) relative to the harmonized estimates. The maps relative errors ranged from 29% to 40% at national level and increased at higher resolutions, reaching 58–67% at pixel level. We also assessed the effect of the harmonization of the national statistics and report that the harmonized biomass values present significant differences compared to the national estimates for 14 countries, and provide a slightly higher stock (+3.8%) at European scale. We show that harmonized and representative reference data are essential to properly assess the accuracy of biomass maps, and we further identify the factors affecting the maps performance and provide indications for their improvements.

1. Introduction

Forests cover 38% of the land area in the European Union (EU) and provide key environmental functions and socio-economic benefits (FOREST EUROPE, 2015). Updated and harmonized spatially-explicit estimates of the forest biomass stocks in Europe are necessary to support the EU policies on bioeconomy and renewable resources, as well as to improve climate change modelling and design appropriate mitigation actions (EC, 2011; Grassi et al., 2017; Nabuurs et al., 2013; Scarlat et al., 2015).

Most European countries have a National Forest Inventory (NFI) providing reliable statistics on aboveground dry biomass of living trees in forest areas (hereafter, biomass) at national scale (Tomppo et al., 2010; Vidal et al., 2016). However, the NFI data are not always recent or frequently updated, often do not provide the spatial distribution of biomass, and are based on country-specific inventory designs and biomass definitions that make their integration difficult for a regional (i.e., European) assessment of biomass resources (Lawrence et al., 2010; McRoberts et al., 2010; Neumann et al., 2016).

During the last decade and mostly independently from the NFIs, a few biomass maps have been produced at European or global scales using different input data and modelling approaches (Barredo et al., 2012; Gallaun et al., 2010; Kindermann et al., 2008; Thurner et al., 2014). These maps provide wall-to-wall biomass estimates over forested areas, but the level of reliability of their estimates is difficult to assess since the remote sensing signals used for the estimations are only indirectly related to the biomass density of vegetation. Moreover, the maps validation is limited by the lack of reference data consistent over the study region and with a spatial resolution comparable to that of the map cells (Hill et al., 2013; Mitchard et al., 2013, Réjou-Méchain et al., 2014).

Hence, there is a need to assess the coherence between “top-down” data from global or regional biomass maps produced by the remote sensing community with “bottom-up” statistics and plots from the NFIs, which are recognized as official estimates at the national and international levels such as for the reporting to the FAO and to the UN

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Framework Convention on Climate Change (Avitabile et al., 2011; Hill et al., 2013; Moreno et al., 2016).

In this study, we use harmonized biomass statistics and field plots for 26 European countries derived by NFI organizations in the context of service contracts launched by the Joint Research Centre (JRC) of the European Commission using a common biomass definition and estimator. This dataset is used to assess the uncertainties of four recently published biomass maps produced with varying degrees of complexity, from simple spatialization of average values using forest and ecozone maps to calibration of satellite and ancillary data using statistical models. Given the large differences in spatial and temporal resolutions between the reference plots (< 1 ha) and the map cells (~1 km^2), an automated screening procedure is implemented to remove the plots not representative of the pixels. This study aims to better understand the capabilities and limitations of existing datasets and related methods, providing important information towards an improved mapping of forest biomass in Europe.

2. Material and methods

2.1. Harmonized biomass data

National statistics on forest biomass based on NFI data are periodically reported for all European countries by the national authorities for regional and global assessment purposes, such as the FAO Forest Resource Assessment (FRA) initiative (FAO, 2015) and the State of Europe's Forest (FOREST EUROPE, 2015). Furthermore, some European countries provide online access to biomass statistics at sub-national levels. However, the biomass data provided by different countries are not directly comparable because they employ: (i) different definitions (i.e., refer to different biomass pools); (ii) different approaches to estimate biomass from the tree parameters (i.e., allometric equations or biomass conversion and expansion factors); (iii) different sampling designs and estimators to compute biomass stock over the study area; (iv) different timeframes as each NFI refers to a specific time period (Tomppo et al., 2010).

Given the need of harmonized forest biomass statistics in Europe, the JRC launched two service contracts in 2013 and 2015 on the "Use of National Forest Inventory data to estimate biomass in the European Forests". These contracts aimed to identify and apply a common biomass definition and estimator and obtain harmonized and comparable biomass estimates at national and sub-national levels for 26 European countries (Henning et al., 2016; Korhonen et al., 2014). The service contracts were implemented in the context of the JRC "Framework Contract for the provision of forest data and services in support of the European Forest Data Centre (EFDAC)", which was also used to derive a harmonized dataset of tree species occurrence for Europe now publicly available (Mauri et al., 2017). Hereafter, the harmonized biomass estimates derived by the 26 participating NFIs organizations (see Acknowledgments) will be shortly referred to as the harmonized EFDAC biomass dataset. The 26 countries included in this study are shown in Fig. 1.

The harmonized definition included all aboveground biomass compartments of living trees, namely the aboveground part of the stump, the stem from stump to top, dead and living branches, and foliage. The common estimator was a design-based unbiased estimator applicable anywhere in Europe regardless of the stratification, point weighting and use of clusters in the original NFI sampling scheme (Lanz, 2012). Biomass was estimated for the areas defined as forest according to the FAO reference definition (FAO, 2000).

2.1.1. Harmonized biomass statistics

The harmonized EFDAC biomass statistics consist of the total biomass stock and its sampling error (in units of Mg), the mean biomass density and its sampling error (Mg ha^{-1}), and the forest area where biomass is estimated (ha). These values were calculated at national level and at the sub-national levels corresponding, for most countries, to the 2010 Classification of Territorial Units for Statistics (NUTS) level 2.

The 26 countries provided four different estimates of the total and mean biomass, obtained using the national or the harmonized definition of biomass in combination with the national or the common estimator. These estimates were obtained from a total of 431,261 field plots located in a forest area of 156 million ha, and were provided for individual species and for species groups (broadleaves and coniferous).

In the present study, the EFDAC biomass statistics were compiled, screened for errors, checked for consistency with published statistics (FAO, 2015; FOREST EUROPE, 2015), and analyzed. Seven countries did not report the sampling error related to the national estimator and in this study it was assumed equal to that of the common estimator. The statistics based on the harmonized definition and common estimator were then used as reference values for the assessment of the biomass maps.

2.1.2. Harmonized biomass plots

Almost half million ground measurements within forest land have been acquired in Europe by several NFIs during the last two decades. However, most of the plot measurements are not accessible to researchers outside the national authorities for privacy reasons. Within the mentioned JRC service contracts, the 26 participating organizations made available a systematic subset of the NFI plots, providing the biomass density according to the harmonized definition and common estimator of one NFI plot for each 8 km INSPIRE grid cell. The plot nearest to the centre of the 8 km cell was selected and provided with a geolocation approximated to the 1 km INSPIRE grid. In total, the subset included 22,166 field plots with an almost complete spatial coverage of the European forests (Fig. 1).

2.2. Biomass maps

2.2.1. Maps description

Currently, there are four published maps providing forest biomass density for Europe: the datasets of Barredo et al. (2012), Kindermann et al. (2008), Gallaun et al. (2010) and Thurner et al. (2014) (Fig. 2). These maps are hereafter referred to with the name of the first author. An overview of the map characteristics is provided in Table 1.

The Barredo map spatializes the IPCC Tier 1 biomass density values per forest type (broadleaves, coniferous) and ecozone using the CORINE Land Cover 2006 map (Bossard et al., 2000) and the FAO Global Ecological Zone (GEZ) map (FAO, 2001), following an approach similar to that presented by Reusch and Gibbs (2008). In addition, the Barredo map further post-adjust the estimates at pixel level by applying ratios to match the national values reported in the FAO FRA 2010 (FAO, 2010). This map provides biomass and carbons stock density for Europe at 1 km resolution for the year 2010.

The Kindermann map downscales the FAO FRA 2010 national biomass statistics using the MODIS Net Primary Production (NPP) annual products (Cramer et al., 1999) and a map of human impact (CIESIN, 2002), assuming biomass linearly related to NPP and inversely related to human influence (Keeling and Phillips, 2007). This map provides biomass density globally at 0.0083° resolution. The map used in this study is the 2010 update (Kindermann, pers. comm.) of the map published in Kindermann et al. (2008), which was based on the FRA 2005 statistics.

The Gallaun map is based on the CORINE Land Cover 2000 map (Bossard et al., 2000), meteorological data (Hijmans et al., 2005) and MODIS images and Vegetation Continuous Field (VCF) products (Hansen et al., 2003), calibrated using NFI plot data from 16 European countries (Nabuurs et al., 2010). The volume estimates were further post-adjusted using correction ratios to match the regional EFISCEN data on growing stock in 2000 (Schelhaas et al., 2007) and converted to biomass using mean regional Biomass Expansion and Conversion